

A brief history of the development of mannequin simulators for clinical education and training

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Simulation for medical and healthcare applications, although still in a relatively nascent stage of development, already has a history that can inform the process of further research and dissemination. The development of mannequin simulators used for education, training, and research is reviewed, tracing the motivations, evolution to commercial availability, and efforts toward assessment of efficacy of those for teaching cardiopulmonary resuscitation, cardiology skills, anaesthesia clinical skills, and crisis management. A brief overview of procedural simulators and part-task trainers is also presented, contrasting the two domains and suggesting that a thorough history of the 20+ types of simulator technologies would provide a useful overview and perspective. There has been relatively little cross fertilisation of ideas and methods between the two simulator domains. Enhanced interaction between investigators and integration of simulation technologies would be beneficial for the dissemination of the concepts and their applications.

out. This can also be called fully immersive simulation. The term "part-task trainer" should be applied to technologies that replicate only a portion of a complete process or system. However, simulator is commonly used in a generic sense to apply to all technologies that are used to imitate tasks. Gaba defines 11 spectra of simulation characteristics.⁴ One spectrum uses the following terms:

- verbal (role playing)
- standardised patients (actors)
- part-task trainers (physical; virtual reality)
- computer patient (computer screen; screen based "virtual world")
- electronic patient (replica of clinical site; mannequin based; full virtual reality)

While most of these types of simulations and simulators are not examined in this history, all will probably be integrated into the restructuring of the education and training processes for clinicians in all domains. That most simulation technologies and techniques for medical and healthcare applications are not examined here is a reflection of how broad the field is already. Even for the areas that are covered, the discussions are relatively brief summaries, describing only key events that can be uncovered.

APPROACH

We searched PubMed for the keywords "simulation" and "simulator" for the years 1965 to 2004. Several summary publications were used as primary sources to other references. Because a substantial body of work was conducted by private corporations, we used several non-referenced sources, including hand searches of many volumes of the proceedings of *Medicine Meets Virtual Reality*. Many other sources of abstracts—for example, other medical and nursing meetings—were not searched because of time and

While still in a relatively nascent stage of development, simulation for healthcare applications has already evolved through its initial historical phases.* Recounting stories of some key simulation technologies could be useful for informing future simulation advocates. In this brief history of medical simulation we focus primarily on the origin of mannequin simulators, especially those employing computer control, and we examine some of the pedagogy and evaluations of effectiveness that aided dissemination. A listing of part-task trainers for surgical and medical procedures (which we refer to as "procedural" simulators) and more limited discussion of their origins are also given to indicate the extent of activity in that area.

DEFINITIONS

Some definitions are needed for this discussion. As there is no accepted convention, those used here are arbitrary, although drawn from suggestions by others. "Simulator" refers to a physical object or representation of the full or part task to be replicated. "Simulation" refers to applications of simulators for education or training. The term simulator is used by some specifically to refer to technologies that recreate the full environment in which one or more targeted tasks are carried

Abbreviations: ACRM, Anesthesia Crisis Resource Management; ASC, Anesthesia Simulator-Consultant; CASE, Comprehensive Anesthesia Simulation Environment; CPR, cardiopulmonary resuscitation; CRM, crew resource management; ERCP, endoscopic resection of colonic polyps; GAS, Gainesville Anesthesia Simulator

*Good and Gravenstein refer to the very early roots of simulation, for instance to the medieval quintain, a mounted figure used for lance practice by horse mounted knights.¹ There is a successful history of simulation in non-medical domains, with aviation most often cited as the example to emulate. That experience has influenced the development of medical simulators, but is described elsewhere.^{2,3}

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resource constraints. Interviews were conducted with several pioneering investigators and developers of technology for procedural simulators.

ORIGINS OF THE MODERN ERA OF SIMULATION

We begin with the earliest published accounts of some part task trainers that are precursors to computer based simulators. Gaba⁵ has produced a detailed history of the development of mannequins and some screen simulators, particularly as they were first used in anaesthesia, and he and his colleagues also reported on a 10 year experience in using simulation for crisis resource management training.⁶ Issenberg *et al* presented an overview of simulators and trainers in several domains.⁷

Resusci®-Anne to SimMan®

While not computer driven and having relatively limited functionality, Resusci-Anne marks a beginning for discussion because it is widely used for medical training and is a progenitor of one of the two current commercial mannequin simulators. Created in the early 1960s, this mannequin for training in mouth to mouth ventilation was designed by Asmund Laerdal, a successful Norwegian manufacturer of plastic toys (fig 1).⁸ He was encouraged to do so by Dr Bjorn Lind and other Norwegian anaesthesiologists, following Dr Peter Safar's revelations about the superiority of mouth to mouth resuscitation.⁹⁻¹⁰ The airway could be obstructed, and it was necessary to use hyperextension of the neck and forward thrust of the chin to open the airway before initiating insufflation of air into the mannequin by the mouth to mouth technique that Safar had described. Based on evidence of the efficacy of closed chest massage,¹¹⁻¹² Safar later advised Laerdal to include an internal spring attached to the chest wall, which permitted simulation of cardiac compression. The possibility of training for the ABC (airway, breathing, circulation) of cardiopulmonary resuscitation (CPR) on the simulator was thus born.¹³ This early simulator of a dying victim, not breathing and lacking a heart beat, became known as Resusci-Anne and has been widely used for CPR training.¹⁴

The Laerdal company did not develop a higher fidelity mannequin until the mid-1990s when encouraged to do so by

many, including Dr Ake Grenvik, a Safar colleague at the University of Pittsburgh. Drs Rene Gonzales and John Schaefer, also of the University of Pittsburgh, developed a more anatomically correct airway and simulator, which was manufactured by Medical Plastics Corporation (MPL) of Texas.¹⁵ Laerdal acquired MPL and developed the simulator, then called SimMan, which was substantially cheaper than other available higher fidelity mannequin simulators, thus altering the market in a fashion described by the disruptive innovation model of Christensen.¹⁶

Sim One

Sim One is a starting point for true computer controlled, mannequin simulators, particularly for simulation of the entire patient (fig 2).¹⁷⁻¹⁹ Conceived by Dr Stephen Abrahamson, an engineer, and Dr Judson Denson, a physician, at the University of Southern California in the mid-1960s, it was built in collaboration with Sierra Engineering and Aerojet General Corporation. Abrahamson, in a video acceptance of an award from the Society for Technology in Anesthesia, described the idea as originating from Aerojet's need to develop peacetime applications of its capabilities in the face of diminishing military funding, before the escalation of the Vietnam conflict. The initial concept of replicating anaesthesia machine functions quickly evolved to the objective of recreating more of the entire patient. After meeting with rejection from the National Institutes of Health and military funding sources, the project to build a prototype was supported by a three year, \$272 000 grant from the US Office of Education.

The simulator was a remarkably lifelike mannequin, controlled by a hybrid digital (with "4096 words of memory") and analogue computer. It had many high fidelity features: the chest was anatomically shaped and moved with breathing, the eyes blinked, the pupils dilated and constricted and the jaw opened and closed. To a limited extent, it was used for training and to conduct some primitive experiments about efficacy. While not rigorously justified by the methods, the authors claimed that the simulator had a "twofold" advantage in training anaesthesia residents in the skill of endotracheal intubation while "posing significantly less threat to patient safety."²⁰

Sim One did not achieve acceptance. Only one was constructed; sadly, nothing remains of it. The computer technology was too expensive for commercialisation. But, equally importantly, the market for training in other than an apprenticeship model was non-existent. Gaba speculates that the vision for the use of Sim One was too narrow to create



Figure 1 Asmund Laerdal with Resusci-Anne, in about 1970.



Figure 2 Dr Stephen Abrahamson (seated) and Dr Judson Denson with Sim One in the late 1960s.

sufficient demand.¹⁹ These pioneers were too far ahead of the technology and the demand for its application.

Harvey cardiology mannequin

Harvey is a full sized mannequin that simulates 27 cardiac conditions. It is the earliest example of the modern concept of a part-task trainer for medical skills training. It was first demonstrated in 1968 at the American Heart Association Scientific Sessions by Dr Michael Gordon of the University of Miami Medical School under the title of a Cardiology Patient Simulator (fig 3).^{21–22} The motivation behind Harvey can be traced to Gordon's days as a cardiac fellow under his mentor, Dr W Proctor Harvey of Georgetown University, after whom the mannequin was named. Inspired by Dr Harvey's use of audiovisuals in his teaching, Gordon built a comprehensive cardiology patient simulator in collaboration with the Center for Research in Medical Education (CRME).²³

The simulator displays various physical findings, including blood pressure by auscultation, bilateral jugular venous pulse wave forms and arterial pulses, precordial impulses, and auscultatory events in the four classic areas; these are synchronised with the pulse and vary with respiration. Harvey is capable of simulating a spectrum of cardiac disease by varying blood pressure, breathing, pulses, normal heart sounds, and murmurs.

Harvey has undergone fairly rigorous testing for educational efficacy, perhaps more than any other simulation technology. Pilot studies documenting Harvey's effectiveness in teaching bedside cardiological examination skills were first reported in 1980.²² In 1987, a study of the use of Harvey among 208 senior medical students in five medical schools was sponsored by the National Heart, Lung, and Blood Institute.²⁴ Fourth year medical students who trained with Harvey during their cardiology elective performed significantly better than their peers who interacted only with patients. This was assessed through skills post-tests using the simulator as well as patients. There were no reported differences in the way patients perceived the professional behaviour of Harvey trained versus non-Harvey trained students. Rather, students who were better able to interpret findings on Harvey showed enhanced confidence and ability to interpret those same findings on patients at the bedside.^{24–25}

Harvey has been used for training medical and nursing students, interns, and residents, and for continuing education of family physicians.^{22–24–28} It has also been applied to

testing bedside cardiovascular examination skills of medical students, residents, and attending physicians in internal medicine, paediatrics, and emergency settings.^{24–29–31} By providing a platform for standardised testing, Harvey was early in allowing for more comprehensive sampling of different skills.

As it matured, Harvey was equipped with a curriculum of cardiovascular conditions, with associated learning goals and data-rich slide programmes developed by a national consortium of physicians and educators.²² It is frequently used in conjunction with the UMedic multimedia computer curriculum, comprising 10 patient centred, cased based programmes, which provides a comprehensive generalist curriculum in cardiology.³²

Around the time in which testing with Harvey was gaining momentum, a separate heart sound simulator was shown to improve cardiac auscultation skills of nurses.³³ Harvey also inspired the development of smaller, more portable cardiology patient simulators, for example, Simulator K.³⁴

Physiological models for realistic simulation

An important contribution to the history of realistic mannequin simulators was the development of mathematical models of the physiology and pharmacology of drugs in anaesthesia. These served a dual function: they evolved into screen based simulators for different applications and also provided the underlying concepts in modelling physiology that were needed to support hands-on simulators with automatic control. Several computer based simulations of various aspects of anaesthesia have been developed. Philip created a program for teaching uptake and distribution of anaesthetic agents, which he called GasMan®.³⁵ Sikorski *et al* described a computer based simulation for instructing anaesthesia residents in managing intraoperative events.³⁶

More complete models of human physiology have enabled higher fidelity, more realistic simulations. Building on the work of others in physiological modelling, Dr N T Smith and colleagues at the University of California San Diego (UCSD) conceived a multicompartment model of human physiology and pharmacology that formed the basis for SLEEPER, a screen based simulator.^{37–39} Intended primarily to teach physiology and pharmacology, it was a fairly complex system requiring more computing power than was then available in desktop computers. SLEEPER evolved into a broader application, BODY™, which was marketed first by Marquette Medical Systems and currently by Advanced Simulation Corporation.

Dr Howard Schwid, a former fellow in the UCSD labs, further developed the concept of screen based simulation by simplifying the models to run on a desktop computer and thus reach a wider audience.⁴⁰ Schwid and O'Donnell also expanded the application to include critical event management, for which there was a greater market^{41–42}; this was commercialised in a product called the Anesthesia Simulator Recorder, marketed in 1989. These workers built an expert system around the anaesthesia simulator to provide learning objectives, management advice, and an automated debriefer. The new program was named Anesthesia Simulator Consultant (ASC). The basic product has further evolved into a family of screen based simulators marketed by Anesoft Corporation. Schwid and others conducted numerous experiments to assess the utility of ASC, including studies of efficacy of learning advanced cardiac life support skills, and comparison of screen based and mannequin simulation learning.^{43–46}

Realistic mannequin simulators

Independently, and for different objectives, two mannequin simulators were developed at approximately the same time at opposite ends of the USA. Both were partly inspired by efforts



Figure 3 Michael Gordon with Harvey in the early 1970s.

to improve patient safety under anaesthesia—a movement that had been inspired by research into error and human factors in anaesthesia and by the formation of the Anesthesia Patient Safety Foundation, which funded simulation research and development in the late 1980s.^{47–49} The pedagogies for employing these simulators have evolved into widely used tools for skills and behaviour training in many domains.

At the Stanford Medical School affiliated Veterans' Affairs Palo Alto Health Care System, Dr David Gaba and colleagues fabricated what is probably the first prototype of a mannequin simulator developed for investigating human performance in anaesthesia. A pre-prototype is shown in fig 4. The original version, used for experiments and training in early 1987, was numbered CASE 1.2 (Comprehensive Anesthesia Simulation Environment).⁵⁰ It combined commercially available waveform generators and virtual instruments—for example, a non-invasive blood pressure monitor—on a Macintosh Plus computer, with a commercially available mannequin to create a “patient” whose vital signs could be manipulated to simulate critical events. Placed in a real operating room and surrounded by actual equipment, this was the beginning of the high realism, physical simulation environment. The next version, CASE 2.0, contained a model of cardiovascular physiology running on a Transputer (a microprocessor chip designed for parallel processing with other such chips), making it partially model driven (as opposed to CASE 1.2) and also an example of parallel processing.⁵¹

The CASE system and its progeny were used by its developers at Stanford and subsequently by others to investigate various aspects of human performance in anaesthesia and related domains.^{52–55} From those experiments, in which critical events were created and the response of subjects observed and measured, emerged a division of performance assessment into technical and behavioural skills.⁵⁵ A training curriculum, Anesthesia Crisis Resource Management (ACRM), based on the then relatively new aviation model of crew resource management (CRM) was also developed, evaluated, and propagated.^{56–57} ACRM teaches generic responses to critical events and incorporates debriefings that use videotapes of simulation scenarios. Course evaluations suggested that the realism was sufficient to elicit realistic behaviours.^{56–58} In 1992, the CASE 2.0 system was transported to Boston, where a series of sessions was conducted to test the feasibility of transferring the educational model.⁵⁹ Anaesthesia faculty, residents, and nurse anaesthetists in the hospitals affiliated with Harvard Medical School were engaged in a 10 week trial. Success there led to the establishment of a collaborative educational centre dedicated to simulation based training—the Boston



Figure 4 Dr David Gaba with earliest CASE pre-prototype, May 1986.

Anesthesia Simulation Center (later renamed to the Center for Medical Simulation)—which was probably the first adopter of the technology for education applications outside the centres that developed the different technologies.

The CASE system and ASC software models were licensed to CAE-Link (a descendent of the original Link Aeronautical Corporation that produced the pioneering “Link Trainer”, the first significant simulator in aviation)” for commercialisation.⁶⁰ The CAE patient simulator used modified physiological models from the ASC models, with large sets of patient characteristics, including cardiovascular and respiratory function, acid-base balance, and pharmacokinetics and pharmacodynamics representing numerous disease states. The mannequin had many features, including airway anatomy that could be altered to mimic degrees of difficulty of intubation, palpable carotid and radial pulses, lungs that simulated behaviour during spontaneous and controlled ventilation, heart and breath sounds, eyes that opened and closed, and a thumb twitch, as used for monitoring neuromuscular blockade during anaesthesia. The system was driven by a Sun SPARC 1 computer, which allowed for automatic responses to drug interventions entered by the operator and for manual manipulation of physiological variables.

The company transmuted several times (from CAE-Link to CAE Medical Electronics, to Eagle of Binghamton, New York), and the product was eventually sold to Medsim Ltd, headquartered in Israel. Medsim, which previously had developed and marketed a part-task trainer for ultrasound training (UltraSimTM) eventually abandoned patient simulation, in part because its marketing strategy to create training centres did not fit the demand of the times.

At around the same time that CASE 1.2 was being born, a multidisciplinary team at the University of Florida, Gainesville, led by Dr Michael Good and mentored by Dr J S Gravenstein, developed the Gainesville Anesthesia Simulator (GAS).⁶¹ It arose from an interest in training anaesthesia residents in basic clinical skills. The project began with the capability for diagnosis of faults in anaesthesia machines, in which controllable mechanical failure modes were embedded. Attaching a lung simulator to the machine extended the training challenge. This was developed into a complete mannequin, aimed primarily toward diagnosis of single source critical events in anaesthesia. The mannequin had a sophisticated lung model, which mimicked uptake and distribution of anaesthetic gases. Later versions incorporated a system for automatically recognising drugs as they were injected. In contrast to the more instructor driven manual operation of CASE 1.2, this software enabled sequences of physiological changes both predefined and in response to actions of the trainer and trainee.

GAS was subjected to an important early test of efficacy, reported only in an abstract.⁶² Sixteen anaesthesia residents were randomised into two cohorts: with and without simulation instruction. Clinical evaluations—in which evaluators were blinded to the subject cohort status—indicated a more rapid learning curve for the simulation trained group, although both groups achieved the same level of proficiency at the end of the three month trial. The trial was ended primarily because of resident demand to participate in simulation training.

GAS was licensed to Loral Data Systems Inc, which later spun off the simulator product to a new company, Medical Education Technologies Inc (Sarasota, Florida). The METI product was dubbed the Human Patient SimulatorTM (HPS). A paediatric version, PediasimTM, and a simpler and more portable model, the ECSTM, were introduced in the late 1990s and early 2000s, respectively.

Other mannequin simulators

Several other mannequin simulators were constructed and used in the assessment of training processes but without becoming commercial products. Chopra *et al* developed the Leiden Anesthesia Simulator as a tool for teaching critical event management in anaesthesia.⁶³ It appears to have been modelled on CASE 1.2 and was used in an experiment to assess the efficacy of simulation based training to improve skills in critical event management.⁶⁴ The Sophus Anaesthesia Simulator was developed in 1991 by a team from the Department of Anaesthesiology at Herlev Hospital, Roskilde University and Risø National Laboratory in Denmark.⁶⁵ Schaefer and colleagues in Basel employed a combination of the Sophus simulator and part-task surgical skills trainer using a perfused pig liver to teach Team Oriented Management Skills (TOMS), developed independently from, but in a similar way to, crisis resource management.⁶⁶⁻⁶⁷ The combined simulator system was called Wilhelm Tell. ACCESS (Anaesthesia Computer Controlled Emergency Situation Simulator) was developed in the United Kingdom as a part-task trainer for anaesthesia skills.⁶⁸

VALIDATION AND ASSESSMENT

Some educators believe that the acceptance of simulation based training will not occur until there is substantial validation of its efficacy and effectiveness in cost-effectively improving learning or patient outcomes. In the realm of mannequin simulation, there have been validation studies demonstrating the interest and enthusiasm of students, high levels of realism, and construct and content validity.⁵⁶⁻⁵⁸⁻⁶⁴⁻⁶⁶⁻⁶⁹⁻⁷¹ There has been only limited assessment of the transfer of training to the real environment and no assessment of effectiveness in reducing risk or improving patient outcomes.⁶²⁻⁷² Important efforts to develop the measurement instruments and rating scales needed to assess performance and behavioural change in simulated or real environments have been described.⁵⁵⁻⁷⁰⁻⁷³ Such measures are required for the validation that may be needed for broader acceptance, although few such measures of outcome improvement—for example, reduction in accidents—are available for simulation in non-medical domains. Gaba has noted many obstacles to obtaining definitive proof of the impact of simulation, including the need to study long term applications of the technology and curricula rather than one shot applications.⁷⁰ He further has observed that “no industry in which human lives depend on the skilled performance of responsible operators has waited for unequivocal proof of the benefits of simulation before embracing it.”⁷⁴

DISSEMINATION OF THE MANNEQUIN SIMULATION CONCEPT

Examination of the publications and discussions with some of the developers suggest that the groups involved in the early phases of the simulators described above were almost entirely independent. The development of CASE was not informed by the models of Schwid or Smith. GAS and CASE developed entirely independently of each other and neither relied on lessons from Sim One (Gravenstein J S, Gaba D M, personal communications). None of the anaesthesia simulators seems to have been informed by the history of development or dissemination of either Harvey or Resusci-Anne. Resusci-Anne on the other hand, appears to have evolved into SimMan as a result of the developing market for mannequin simulators that was stimulated by METI's and Medsim's patient simulators.

Once the more recent simulators took their initial form, interactions between the various developers occurred at least in part as a result of conferences focusing on simulator and simulation research. The earliest conferences were organised

by the FDA and the Anesthesia Patient Safety Foundation in 1988 and 1989.⁷⁵⁻⁷⁶ A broader conference, “Simulators in Anesthesiology Education”, was held at the University of Rochester (New York) in 1995. In 1998, the Society for Technology in Anesthesia and what was then called The Rochester Simulator Symposium jointly sponsored a meeting. The following year, the first international meeting on medical simulation was held. The Society in Europe for Simulation Applied to Medicine (SESAM) was formed in 1994. More recently, the Society for Medical Simulation (SMS) was organised. The meeting named “Medicine Meets Virtual Reality”, first held in 1991, has been a focus of interactions primarily for virtual reality and procedural simulation, although some mannequin simulation work has been presented there. “The International Conference on Medical Image Computing and Computer-Assisted Intervention”, a merger of three technical and scientific meetings, was first held in 1998 and is a venue for presentation of scientific and technical concepts underpinning simulation. All of these meetings have probably facilitated dissemination and cross fertilisation of the early conceptual developments. However, there has been relatively little overlap of topics and investigators between the various conferences.

BRIEF COMMENTS ON PROCEDURAL SIMULATION

Although the field of procedural simulation is also still in early stages of growth and the technology penetration is minimal, there are already many computer based part-task trainers for a spectrum of surgical and interventional tasks.⁷³⁻⁷⁷ We have identified over 20 types of skills training devices that have been described in published reports, many of which are in various stages of development or marketing (table 1 gives a list of early references to each type). At the time of writing, there has been no comprehensive review of this component of the medical simulation field. Publication of the early developments appeared at about the same time as the early developments in mannequin simulators, perhaps the earliest report being in 1987 by Gillies and Williams for fibre-endoscopic training.^{78*} Baillie *et al* described a computer simulation for teaching basic ERCP techniques in 1988.⁷⁹ A trainer for catheter insertion developed by HT Medical, formerly Hightechsplinations, was one of the earliest practical devices to be developed, although literature citations did not appear until later⁸⁸ (Meglan D, Foster Miller Corporation, personal communication). Satava has written about some of the early simulators for laparoscopic surgery.⁷⁷ Key funding of surgical simulation was catalysed substantially by funding from the Defense Advanced Research Projects Agency (DARPA).

Studies of transfer of training of skills to patient care for procedural skills trainers could be a pivotal historical point in the broader adoption of simulation concepts for all forms of simulation. Taffinder *et al* demonstrated the validity of the MIST VRTM (Minimally Invasive Surgical Trainer Virtual Reality) simulator in differentiating experienced from novice surgeons.¹⁰¹ Also using MIST VR, Seymour *et al* showed that basic skills improved performance of residents in laparoscopic cholecystectomy.¹⁰² There have also been some studies demonstrating that surgical skills training devices can be used to assess proficiency in psychomotor skills.¹⁰³

Given the large number of procedural simulators and trainers developed for different medical domains, the history of how each was spawned and evolved is likely to be rich in interesting stories. The contrasts and similarities of evolution

*As the original sources of many procedural trainers were from corporate research and development versus the generally academic source of most mannequin simulators, publications are less indicative of the chronology of development or appearance of specific technologies.

Table 1 Listing of types of simulator by earliest identified date of reference

Simulator	Date of first publication
Fibre-endoscopy ⁷⁸	1987
ERCP ⁷⁹	1988
Colonoscopy ⁸⁰	1990
Endoscopic trainer ⁸¹	1993
Laparoscopic surgical simulator ⁸²	1994
Hysteroscopy ⁸³	1994
Hollow organ closure ⁸⁴	1994
Total hip replacement ⁸⁵	1995
Ophthalmic simulator of laser photocoagulation ⁸⁶	1995
Ophthalmic surgery simulator ⁸⁷	1995
Intravenous catheter insertion ⁸⁸	1996
Otolaryngology ⁸⁹	1996
Laparoscopic surgery ⁹⁰	1997
AAA endovascular repair ⁹¹	1998
Virtual simulator for inferior vena cava filter placement ⁹²	1998
Sigmoidoscopy ⁹³	1998
Shoulder arthroscopy ⁹⁴	1999
Surgical suturing ⁹⁵	1999
Breast biopsy simulation ⁹⁶	1999
Transurethral prostatic resection ⁹⁷	1999
PC based interventional cardiology simulator ⁹⁸	2000
Bronchoscopy ⁹⁹	2001
Upper gastrointestinal endoscopy ¹⁰⁰	2003

AAA, abdominal aortic aneurysm; ERCP, Endoscopic Retrograde Cholangiopancreatography.

between procedural, mannequin, and other simulation modes could be informative of how innovation is catalysed, evolves, and diffuses in healthcare education and training.

DISCUSSION

The history of mannequin simulators suggests that the early years were marked by several parallel, almost entirely independent developments that pursued somewhat different objectives and led to differences in technical approach. Resusci-Anne was developed specifically for practice in a specific skill, CPR. Harvey was born out of a desire to teach skills in cardiac diagnosis more effectively. CASE and CRM were motivated by an interest in safety and especially in the study of human performance. GAS, also from a patient safety perspective, was primarily intended to teach basic clinical skills and diagnosis in anaesthesia. Essentially all of the original simulators and simulations have evolved into products or concepts that are currently enabling changes in healthcare education and improvements in patient safety. Future prospects are good for simulation, simulators, and part-task trainers to have a strong, positive impact on healthcare, especially by lowering the risk to patients of training, by providing a method of learning about care processes, and by helping to establish a strong culture of teamwork and collaboration within the clinical workforce.

This review of the literature of both mannequin and procedural simulation suggests that there is relatively little overlap of source material references between the major domains. While there are clear differences in applications, technologies, and approach, there are many similarities in pedagogy and methods for validation and dissemination. That there is so little cross fertilisation between the various simulation camps may suggest gaps in collaboration that could be hampering broader discovery, innovation, and dissemination. That is further evidenced by the existence of different professional meetings for mannequin and procedural simulators and perhaps even a lack of appreciation of the potential synergy between the various simulation modes. There have been some examples of the value of integration of procedural and mannequin simulators for team training.^{66, 104}

Key messages

- The modern era of mannequin simulators developed from several different roots and for different applications.
- There are now at least 20 different types of task trainers for medical procedures available or in development.
- There has not yet been much cross fertilisation between the academic developers of the procedural and mannequin simulator technologies.
- Integration of procedural and mannequin technologies is needed to enable full team training to achieve the broadest potential of simulation.
- Becoming broadly familiar with the technologies, pedagogies, and research methods in each domain within the field will serve to better inform strategies and tactics for application and diffusion of simulation into healthcare education, training, and research.

This concept should be extended to enable full team training for all varieties of clinical teams.

Simulation in healthcare education and training appears to be gaining acceptance, but it has not yet reached what would be called a "tipping point"¹⁰⁵ of widespread adoption. There is still relatively low penetration of the entire market of medical and healthcare education. While many are in use, they are still the exception, not the rule, for healthcare education and training. Technical developments may be limiting, but the greater limitation derives from the model for reimbursement for healthcare and education in industrialised countries. The lack of research showing effectiveness, transfer of training to the clinical environment, and cost-effectiveness are also barriers to diffusion of the technology.

It is not yet certain that the next historical phase of simulation will achieve the acceptance and dramatic growth that are needed to lead a radical change in healthcare education and contribute substantially to patient safety. Collaboration and greater interdisciplinary research across simulation domains than has yet occurred could be synergistic and leverage the efforts of all. We suggest that everyone working in the field become broadly familiar with the technologies, pedagogies, and research methods in each domain to better inform strategies and tactics for application and diffusion of simulation into healthcare education, training, and research.

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